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Assessment of the Conservation Status of Natural and Semi-Natural Patches Associated with urban Areas Through Habitat Suitability Indices

Natale, E.[1*], Villalba, G.[1], Junquera, J. E.[1] and Zalba, S.M.[2]

[1]Fundación Conservación y Desarrollo, ConyDes, Sobremonte 1653 (5800) Río Cuarto, Córdoba, Argentina

[2]GEKKO, Grupo de Estudios en Conservación y Manejo, Departamento de Biología, Bioquímica y Farmacia, Universidad Nacional del Sur, Bahía Blanca, Buenos Aires, Argentina

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ABSTRACT: Urban environments rely on the surrounding natural ecosystems remnants as providers of ecosystem functions, therefore these areas not only support a unique biodiversity but also have a social value for maintaining public health and wellbeing. For this reason, urbanization is considered to be one the biggest threats to ecosystems, leading to native biodiversity simplification and, thus, to a detriment of the provided ecosystem services. Moreover, this change in land use results in high levels of landscape fragmentation and modification in areas surrounding the habitat remnants which, in consequence, become inadequate for many native species. In this context, it is important that urban planners have the information to assess the possible consequences of future changes in land use in order to increase the landscape chances of supporting both, native biodiversity and the needs of a growing human population. The objective of the present work is to evaluate the ecological integrity of natural and semi-natural vegetation patches immersed in an urban area in order to generate a conceptual framework for landscape assessment that allows urban planners to envision the best choice for city development at a given place. To do so, we developed a quantitative integral environmental evaluation index that includes ecological characterization, geological characterization, and environmental characterization (presence of anthropic disturbance) of the assessed area. We conclude that the index we have generated in this work is suitable to be used as a management tool to allow an unbiased valuation and to identify managing situations that require a short term response.

Key words: HSI, Urban planning, Landscape, Biodiversity, Sustainable development

INTRODUCTION

Urban areas around the globe are characterized by high population densities and a network of non-natural, built-up infrastructure. Although they only occupy about 3% of the earth's land surface, urban growth imposes major challenges to biodiversity by driving pollution dynamics and altering the structure and function of natural ecosystem (Escobedo *et al.*, 2011). Accordingly, as the human population grows extraordinarily, particularly in developing countries, so do conflicts with conservation aims (Kowarik, 2011).

It is well known that urban ecosystems including, cities, suburbs and towns, rely on their inner or surrounding natural or semi-natural vegetation remnants for ecosystem functions such as air filtering, temperature amelioration, and water storage, filtration and drainage (Li *et al.*, 2005).

From this perspective, natural and semi-natural vegetation patches within urban areas acquire economic, environmental and social value by sustaining public health and wellbeing as well as contributing to conservation by supporting a unique biodiversity (Lawson *et al.*, 2008; Escobedo *et al.*, 2011). In addition to this, the global biodiversity crisis affecting the planet is mainly the result of changes in land use caused by human activities (Gordona *et al.*, 2009; Jordán *et al.*, 2003). This crisis is characterized by expanding road networks, human settlements, resource extraction and other encroachments on the landscape that have increased fragmentation and loss of natural areas (Crist *et al.*, 2005; Pauchard *et al.*, 2006). This effect becomes even more evident in urban and peri-urban areas, where the natural habitat left is not suitable for many native species. For this reason, urbanization is considered to be one of the greatest threats to biodiversity leading to the simplification of native ecosystems (Jaeger *et al.*, 2010; Pauchard *et al.*, 2006).

*Corresponding author E-mail: evangenatale@yahoo.com.ar

South America has not escaped the urbanization trend and follows current models of urban development, where urban areas are expanding and replacing rural and natural areas (Galafassi, 2013). Although the degree of development in South America is far less pronounced than in the developed countries including in United States or Europe, urban sprawl has, nevertheless, a major impact on peri-urban ecosystems (Pauchard *et al.,* 2006; Izquierdo & Grau, 2009). Mitigation of the impact that city -growth has on natural processes and systems such as air filtering, temperature amelioration and water storage, is challenging due to the high economic value of the land and the diversity of the stakeholders that generates conflicts of political, economic and social interest (Gordona *et al.,* 2009). Therefore, urban environments offer an opportunity to combine ecological management with landscape design, in order to provide a variety of services and goods (Williams *et al.,* 2009). In this context, it is important that researchers, land managers and other stakeholders have the information to assess, rapidly and critically, the possible consequences of establishing diverse land use scenarios in order to increase the landscape capabilities of supporting both, native biodiversity and the needs of a growing human population (Turner *et al.,* 2007). Extensive literature supports the concept that effective landscape-scale conservation relays on the information available about the extension, spatial configuration, composition and habitat quality of natural vegetation patches (Scolazzi & Geneletti, 2012; Zerger *et al.,* 2009). The habitat condition depends on its surroundings, which are defined by means of the extension of the anthropic modifications (Manley *et al.,* 2009), the number of patches and their relative abundance (Jordán *et al.,* 2003), and the intensity of land use (Thackway & Lesslie, 2006), among others . Altogether, the condition of vegetation patches in cities is a result of environmental variation, historic disturbance (Apan *et al.,* 2002), native vegetation resistance to variations and its restoration capability (Manley *et al.,* 2009) and geologic dynamics (Vilches, 2012).

For this reason, landscape analysis should constitute a tool used to assess, simultaneously, several ecosystem properties in a suitable spatial scale improving, consequently, the analytic capability of urban design (Sandström *et al.,* 2006; Cadenasso *et al.,* 2007). Accordingly, there is a pressing need of assigning metrics and values to the natural resources to be able to use them in territorial planning projects. Therefore, it is of great importance to develop indices and, in consequence, territorial models that are embedded in a Geographic Information System (GIS) environment (Van der Biest *et al.,* 2014; Branquart *et al.,* 2008).

The aim of this research was to develop a quantitative index using a geographic information system in order to assess the ecological integrity of natural and semi-natural vegetation patches in urban areas. The developed index, which integrates biological, geological and hydrological variables as well as variables of anthropogenic activity, results in a territorial assessment that can be easily interpreted by users that lack specific background. Hence, the model can be used as a tool to generate different land management scenarios (Van der Biest *et al.,* 2014) that allow urban planners to choose the best options for the local urban development, taking into account features, needs and potentials of the natural resources of the area and optimizing the ecological, economic and social benefits. Finally, to illustrate the use of this index for landscape conservation planning we present an example of its application in Villa de Merlo City, Argentina.

MATERIALS & METHODS

The criteria used for the development of the Evaluation Index, hereafter called Integral Environmental Evaluation Index (IEEI), is based on the concept that an environmental or ecological status includes structure, function and all ecosystem processes, provided by physical, chemical, geographical, and climatic factors in combination with the anthropogenic impact and the human activities on a particular area (Galparsoro *et al.,* 2009). The ecological evaluation and the evaluation of the anthropic disturbance were related by means of an integral environmental evaluation index that was developed following US Fish and Wildlife Service methodology (1980) for the development of habitat suitability index (HSI) adapting it to landscape scale. It is worth highlighting that these models are used as species management tool for impact evaluation and in ecological restoration studies (Burgman *et al.,* 2001; Van der Lee *et al.,* 2006). In general, these models describe the relationship between different ecological variables where they estimate the habitat suitability for a particular species using a scale that ranges from 0 (unsuitable habitat) to 1 (maximum habitat suitability) (Chen *et al.,* 2009).

The defined ecologic variables are represented by a single suitability index (SI) and all the SI corresponding to the different variables are integrated through mathematical algorithms (i.e. additive, multiplicative or logical) that express the relationship existing among the considered habitat features (Burgman *et al.,* 2001) composing the Habitat

Suitability Index. The resulting index was applied to the case study Villa de Merlo City (lat. 32°20' 46.99"S/long. 65° 0' 26.98"W) located on Comechingones mountains in the central area of Argentina with an extension of 58 km^2. Because this dry forest ecosystem has shown important urban growth in the last decades resulting in a matrix of built-up area and relicts of natural environments, Villa de Merlo provides a great opportunity to introduce an urban design where development and conservation coexist in equilibrium.

In order to implement the Integral Environmental Evaluation Index (IEEI) the ecological status and the impact of the human activities was assessed for each environmental unit. These values were obtained directly through visual analysis of satellite imagines from Google Earth (Quick Bird), an Aster image with a resolution of 15x15m and the Argentinean Geographic Information System in a 1:250.000 scale (IGM 2004). For the geological variables, a mosaic of the corresponding satellite imagines were used to build thematic maps from where the variable values were acquired. To obtain the environmental units (Gómez Orea & Gómez Villarino, 2013) the following protocol was implemented using the ENVI 4.2 and ArcGis 9.2: 1-Unsupervised visual classification: automatic search for homogeneous spectral groups of values within the image; 2-Field verification: 48 points of image verification were obtained and subjected to field surveys which consisted on 1km transects that assessed the cover-abundance of the plant species for the physiognomic-structural description; 3-Supervised visual classification: the first classification was adjusted and environmental units were defined.

RESULTS & DISCUSSION

To perform the ecological evaluation of a patch the selected variables were: patch size, shape, type of patch and type of contact of the patch with the border (Table 1). In order to define the values of the variable type of contact we considered flora and land cover contrasts. The variable patch shape had a high when the shapes showed a border/interior relation that minimizes the border effect (Crist *et al.*, 2005; Forman, 1995). In order to define values for the variable patch type, it was considered that environmental patches change slowly, reflecting the stability of the substrate; however, remnant and disturbance patches change relatively rapidly, reflecting the rate of succession, and disappear when they converge in similarity with the adjacent vegetation (McElhinny *et al.,* 2005*;* Forman, 1995). Likewise, for the patch size variable it was considered that large patches provide greater benefits and small patches provide supplemental benefits (Jim & Chen, 2009; Forman, 1995). The ecological functionality was assessed by considering the patch role within the landscape, particularly when fulfills the corridor function (Williams *et al.,* 2005; Turner *et al.,* 2007). The geo-environmental complexity of the area was assessed according to the criteria proposed by Gómez Orea and Gómez Villarino (2013). For this, two variables were defined, a geological singularity value (particular constitutive elements of the landscape) and a protection value that comprised natural threats to society or natural environmental fragility, where the highest value represented the most unfavourable situation.

To assess the degree of anthropic disturbance the following variables were selected as indicators of the most frequently found pressures at the peri-urban environment: road presence, settlement presence, tree thinning, tree clearance and percentage of invaded surface. In order to delimit the thresholds of the variable percentage of invaded area it was considered that from the arrival of a new species to its establishment and dispersal, the consequences of invasions increase over time. Furthermore, if the species is detected while populations are still relatively small and restricted in space, the chances of controlling its expansion are significantly higher (Natale *et al.*, 2013). Therefore, starting at 1% of invaded area the aptitude value of this variable drops considerably.

Finally, for each variable adequacy tables were constructed (Robinete & Croizier, 1976) setting critical thresholds to define the condition of the patch: very good, good, regular and bad (Tables 2 - 3). The thresholds were defined based on the carrying capacity obtained through field evaluation of the studied territorial system (Gomez Orea & Gómez Villarino, 2013).

Once the thresholds were defined, they were quantified by creating for each variable a single evaluation index (SI) (Fig.1) and finally the indices were integrated through mathematical algorithms into a general equation to show the interaction between variables.

Thus, the Integral Environmental Evaluation Index was constituted as follows: First, variables describing the **impact of human activities** on patches were related. As shown in equation 1 road presence (Rp), settlement presence (Sp), tree thinning (Tt) and tree clearance (Tc) have a compensatory relation because the impact that one of the variables has on the patch can be as high as the one imposed by a conjunction of

Table 1. Variables used in the ecological assessment of the vegetation patches, according to the proposed by Forman (1995)

Patch Type	Patch Shape	Type of contact
Disturbance (DIS)	Natural Regular(NR)	Floristic natural (FN)
Remnant (REM)	Anthropic Regular (AR)	Floristic introduced (FI)
Environmental (ENV)	Natural irregular (NI)	Structural natural (SN)
Regenerated (REG)	Anthropic Irregular (AI)	Structural Anthropic (SA)
Introduced (INT)	Elongated (ELO)	

Table 2. Thresholds of the variables used for the ecological assessment

Variables	Very Good	Good	Regular	Bad
Patch size	≥ 51 ha.	40 to 50 ha.	10 to39 ha	< 10 ha
Patch shape	NR or NI	AR	ELO	AI
Type of Patch	ENV	REM	REG or DIS	INT
Type of contact	>60% FN	>60% SN	-FN and SN -FN and SA/FI	-SN and FI/SA - > 60% FI/SA
Geological singularity value	Function of particular relevance to the ecosystem	Function relevant to the ecosystem	Function of low relevance to the ecosystem	Function indifferent to the ecosystem
Protection value	Tree geological variables with high or medium susceptibility value	Two geological variables with high susceptibility value and one with intermediate value	One geological variable with high susceptibility value and at least two with intermediate value	Two or more geological variables with low susceptibility value

Table 3. Thresholds of the variables used in the impact human characterization

Impact	Very good	Good	Regular	Bad
Road presence	0 to 1 secondary road	2 secondary roads	3 to 4 secondary roads	5 o more secondary roads or 1 main road
Settlements presence	0	1	2 or 3	>4
Percentage of invaded surface	0% to 0,9%	1% to 15%	15% to 30%	>31%
Tree clearance	< 5%	5% a 15%	16% a 30%	> 31%
Tree thinning	< 10%	10% a 20%	20% a 50%	> 51%

several variables (USFWS, 1980; Gibbs *et al.*, 1998). The effect of road presence depends on the width, kind (paved or unpaved), and intensity of vehicle transit along the road. In this proposal it has been accounted as for small to medium size unpaved roads, but it could be easily adjusted for heavier transit just by weighting this variable in index 1. The same applies for settlement presence (or degree of urbanization) and tree thinning. While for the percentage of invaded surface (PI), the relationship is limiting because of the intensity of the impact that this pressure, on its own, has on patch quality (Simberloff *et al.*, 2013; Didham *et al.*, 2007). Equation 1 is intended to account for habitat degradation, both by fragmentation (affecting the matrix surrounding remnants of native vegetation) and also by losses in habitat quality directly affecting the remnants.

$$\text{Impact (Im)} = [((Rp + Sp + Tt + Tc)/4)^{*} Pi]^{1/2} \qquad (1)$$

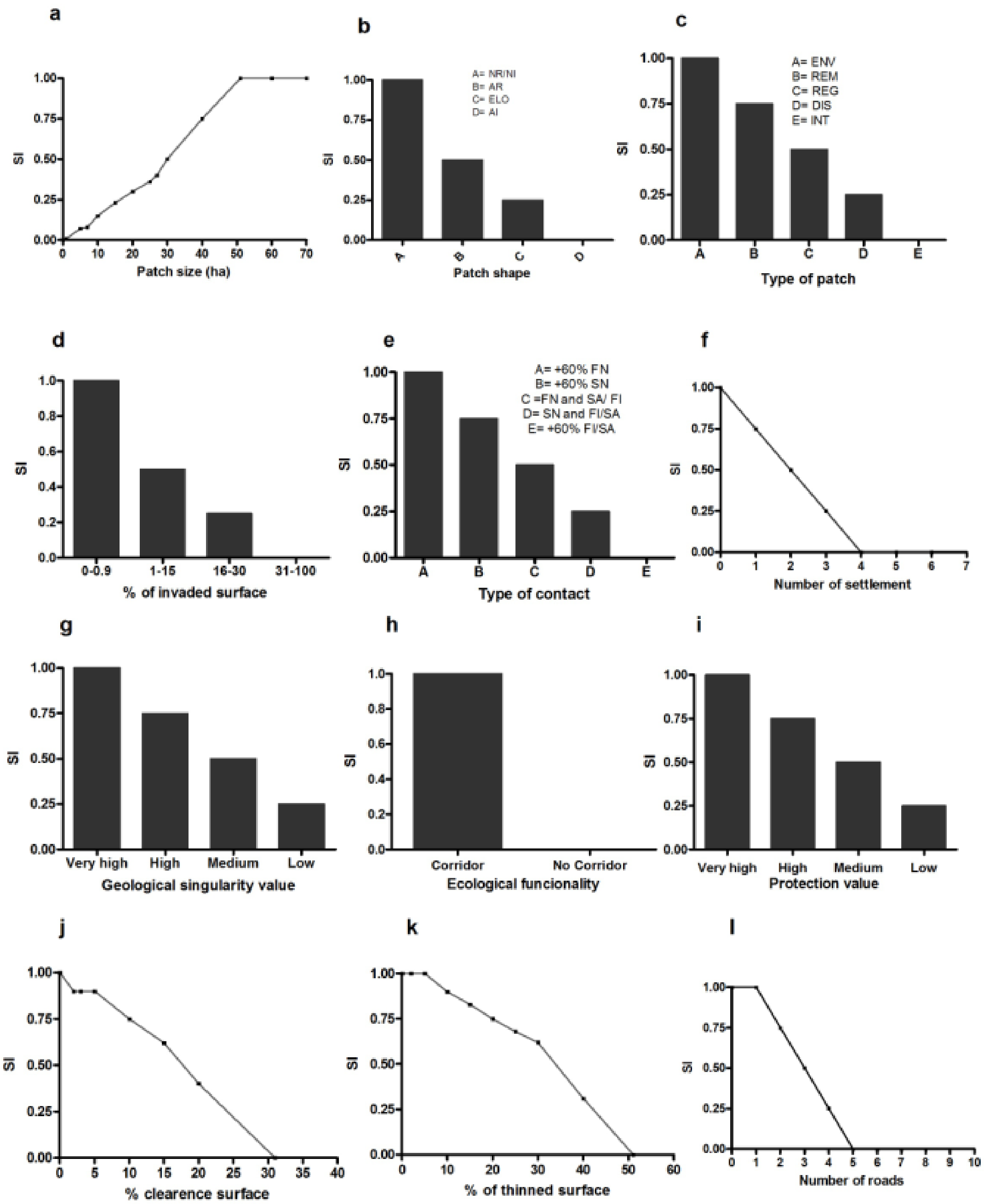

Fig.1. Graphics representing ecological variables individual evaluation indices, including patch size (a), patch shape (b), type of patch (c), percentage of invaded surface (d), type of contact (e), number of settlement (f), geological singularity value (g), ecological functionality (h), protection value (i), percentage of clearance surface (j), percentage of thinned surface (k), number of road (l)

For those variables reflecting the **ecological status** of the patch (equation 2) a compensatory relationship was also determined between the variables patch shape (pSh), patch type (pT) and type of contact (Tc). On the other hand, because of the importance of the variable patch size (pSz) for the maintenance of a viable population, a limiting relationship was assigned to this variable (McNeill & Fairweather 1993).

$$\text{Ecological status (Es)} = [((pSh + pT + Tc)/3) * pSz]^{1/2} \quad (2)$$

In addition, the variables protection value (Pv) and geological singularity value (Sv) that constitute the **Geological value,** were also associated through a compensatory relationship (equation 3) **.**

Geological value (Gv) = (Pv + Sv)/2 (3)

To consider a patch in adequate environmental status it should present an acceptable value of the described components, for this reason a limiting relationship was defined for the three components in the equation 4. Different weights could be assigned to these variables depending on the specific objectives, vulnerabilities and/or the ecological value of the assessed area.

Partial index (Pi) = $(Im*Es*Gv)^{1/3}$ (4)

Finally, equation 5 defines the **Integral Environmental Evaluation Index (IEEI)** by adding to the equation 4 an additional value representing its functionality as biological corridor (Fe). This value clearly depends on the taxon or group of taxa of particular interest, but, in general terms, it can be assessed considering the width of the corridor, its importance (as measured in equations 1 and 2 of the patches connected by it), and the structure and diversity of its vegetation (Beier *et al.,* 2008).

IEEI= Pi + (Pi*0.1*Fe) (5)

The IEEI values fluctuated between 0 and 1, where 0 to 0.44 was considered bad condition, 0.45 to 0.64 a regular condition, 0.64 to 0.84 a good condition and 1 a very good condition.
Based on the vegetation analysis and the analysis of the geological an geomorphical features, 66 patches were relieved and were assigned to one of the 5 environmental units: grassland (cuspidal area), Mollar (forest formation - preferential recharge area), Romerillal (shrub formation - medium fans and rocky blocks raised by faul lines), transition forest and Espinal (xerophytic forest formation - alluvial plains) (Burkart *et al.,* 1996) (fig. 2a).

The preferential recharge area of the aquifer was selected as singularity value for the geological value since it constitutes an integration point for superficial and underground systems, which are connected and become part of the aquifer that provides water for human consumption. The susceptibility values included in the protection value were seismic activity and occurrence of gravitational and alluvial processes, which constitute the main geological activity detected in the studied area (Table 4 & Table 5).

Next, the suitability index of each single variable was determined for each vegetation patch and finally the IEEI value was obtained for each environmental unit (fig. 2b). The analysis showed that both grassland and mollar are the most conserved vegetation units, showing low fragmentation and high pristine nature, next are the romerillal and the south-east transition zone, Chaco-Espinal, which also present patches of considerable surface showing environmental continuity to the east side but anthropic discontinuity to the west. The north-west zone of the Chaco-Espinal transition presented a lower conservation value (regular to bad) caused by the presence of higher number of smaller patches resulting from the city growth on the mountainside that generates a great discontinuity on the natural landscape.

Last is the Espinal with two different conditions: in the north the Espinal has almost disappear due to the emplacement of the city of Merlo, remaining only

Table 4. Thresholds of the variables used in the singularity value for Villa de Merlo

Variable	Very good	Good	Regular	Bad
Recharge value	permeable materials	Slightly permeable materials	Poorly permeable materials	impervious materials

Table 5. Critical threshold defining the susceptibility values for Villa de Merlo

Susceptibility value	High	Medium	Low
Alluvial processes	On water courses with abundant signs of water erosion.	Near water courses with rare signs of water erosion	Away from water courses with no signs of erosion.
Gravitational processes	Slopes greater than 30% with signs of erosion.	Slopes of 30-15% with signs of erosion	Slopes smaller that 15% with no signs of erosion
Seismic processes	On active faults	Near active faults	Away from active faults

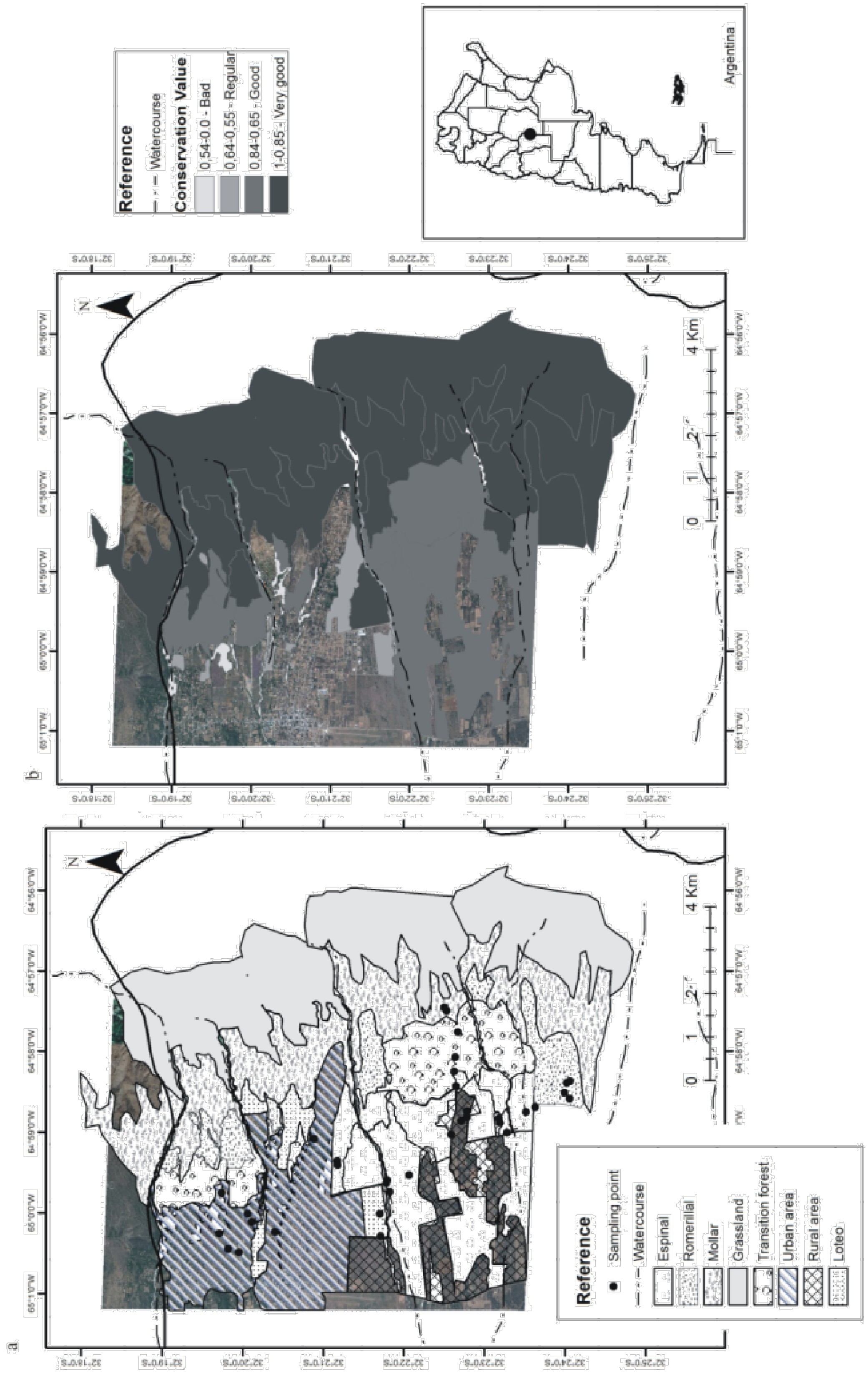

Fig. 2. a) Map of environmental units from the city of Villa Merlo, San Luis; b) Patches valoration by means of appliying the integral environmental index

patches smaller than 5ha immersed in the urban matrix, showing, in general, high degree of invasion and therefore the lowest conservation category (bad); however, in the south, few patches of greater extension are found due to the type of anthropic activity present (farming). The regular condition of these patches is caused by the presence of anthropic irregular borders, high percentage of the surface under recovery (presumably abandoned) and mainly structural anthropic contact.

In summary, over 60% of the patches showed a high conservation value, the reason for this is that those patches that present a low ecological state value (including the anthropic impact) also have a high geological value. The geological value overcame the ecological status in the north-east and in the south-east areas, bearing the highest physical susceptibilities. In general, this antagonistic effect with the ecological status shows the importance of vegetation for the control of geological phenomena of erosive nature. The following usage recommendations were originated from this evaluation, which were taken by planners and incorporated into the regulation standards of the territorial system (Sprechmann & Capandeguy, 2009).

CONCLUSIONS

The methodology employed in the present work allows the study of greater land extensions at lower economic cost and in shorter periods of time. Obtaining quantitative data allows us to quantify the possible environmental impact produced by the execution of a particular land use project and provides useful information to perform two types of comparisons: 1) the relative value of different areas at same point in time and; 2) the relative value of an area at different time points (Galbraith *et al.*, 2004; U.S. FWS 1980). In this study we worked on the first type of comparison by making a quantitative valuation of vegetation patches to finally define the zoning of the studied area. The second type of comparison could be applied by following a monitoring protocol to assess what are the effects of the planning process on the evaluated patches over time. In order to define this protocol the planner will have to select what indicators to measure (sensitive to the concern factor), how to measure them, and the frequency of data collection (Europarc, 2005).

The integral environmental evaluation index (IEEI) could be improved by including other variables that contemplate more specific issues about the vegetation such as different strata coverage, richness and diversity indexes and variables of key species habitats (threaten species, endemic species, etc.) thus allowing a deeper evaluation of the system, according to Saura and Pascual-Hortal (2007). On the other hand, this would require more extensive field work and consequently more time. Therefore, including this type of variables in the index should be analyzed in terms of costs-benefits when urban planning projects are developed.

Although it was not the aim of this work, following Scolazi and Geneletti (2012) we present an index based on the concept of structural connectivity (measured through the landscape structural analysis and not the organisms attributes) which is faster and easier to evaluate. This allows land use projects, which are generally of short term execution, to obtain fast answers at low costs.

A measure of the functional connectivity, which takes into account the organism behavior in response to different elements of the landscape, could be used in latter stages to monitor the effect produced by the implementation of a particular land use project. Accordingly, a variety of indices have been developed to evaluate habitat connectivity and fragmentation. Most of them require gathering information about specific habitat requirements for the evaluated area. One of the most accepted indices is the Probability of Connectivity Index proposed by Saura and Pascual-Hortal (2007), which can only be applied on a particular species and is based on the concept of its habitat availability. This is ideal for places or scenarios where detailed information of the studied area and its biodiversity is available, or where there is no time pressure to collect all the data required to apply the index.

However, there are many regions, particularly surrounding urban areas, where this type of information may not be available, or particular situations where there is no time to perform detailed basic research to obtain the necessary data. In this context, the index proposed in the present work could be of great value, since it integrates in a holistic manner factors that impact on the ecological status of vegetation patches, thus providing a simple management tool to easily deal with urbanization processes that require fast environmental diagnosis. This index could be extrapolated to other fields of study, although it should be noticed that variables that integrate the geological and anthropological disturbance should be adjusted to fit the particular features of the system under assessment.

In the particular case of Villa de Merlo, taking into consideration the east-west direction, we found that the patches could also be acting as corridors, by restoring the effects that urbanization has on the fauna movement among different vegetation units. The identified patches exerting corridor function could be important because of their ecological role and their contribution to the landscape structural connectivity, since they could constitute refuge areas or stepping stones for wildlife.

For these reasons intervention in these environments should take into account environmental and landscape parameters that encompass low intrusive and sustainable use, and consider the establishment of a "green-areas network" that ensures the ecological functionality.

Finally, the present index allows the quantification of the conservation status of the environmental units and can be translated into a GIS platform to define scenarios, by means of different intervention choices, where the planners may establish, based on the objectives and available resources, the option that fulfils better the population needs, the territorial system and its natural components.

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